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ABSTRACT

This paper is a description of a college course in structural design, which in this case serves as the capstone of the program in Civil Engineering Technology at the College of Staten Island (New York). Fourteen weeks of class lecture topics, activities, and assignments are delineated. Coverage includes building codes, loads calculation, structural behavior, and design of beams and columns. The course description also provides the purposes and requirements of a term project in structural design. The course received highly positive evaluations from participants, many of whom remarked on the success of course materials and the term project progressing in parallel throughout the semester. (BEW)

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Teaching Structural Design in Civil Engineering Technology

by Ashraf Metwally

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Teaching Structural Design In Civil Engineering Technology

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General

Structural Design has been taught in Civil Engineering Technology since the program was first introduced in The College of Staten Island. This course has three prerequisites: Statics, Strength of Materials, and Structural Drawings. Traditionally, this course was taught almost as two separate parts by two different professors. One instructor use to teach the Design of Steel part, while the other took charge of the Design of Reinforced Concrete part. Each instructor use to assign a term project where the students had to design two separate buildings; one in steel, and another in concrete.

In the Spring of 1994, I took the responsibility of teaching this course. The course outline, the content, and the sequence of the topics were modified in such a way to assure that the students will fully understand and be able to apply the principles of structural design. In addition, one term project that includes both steel and reinforced concrete design replaced the old procedure of assigning two separate projects. In this paper, the course outline and the term project will be described in detail. Also, the philosophy behind their contents will be analyzed, along with a discussion of the extent of success of this revision.

Introduction

Structural Design is a course taught at the end of a two-year ABET accredited program in Civil Engineering Technology. It is a four-credit course that emphasizes the analysis and design of simple concrete and steel structures. The course meets twice a week for a total of six hours. Structural Design is a comprehensive course that involves the application of all the principles of

mechanics and strength of materials. The main purpose of this course is to illustrate a unified approach to the fundamentals of structural design in Civil Engineering. Practical applications are selected to provide an understanding of the philosophy behind the code provisions.

Structural analysis concepts are reviewed to the extent that they are essential for an understanding of the design and construction situations in question. Similarities of many ideas in structural design and code provisions are presented in a simplified manner. The design of structural steel and reinforced concrete structures is presented in this course according to the latest code provisions. As a practical application, a term project is assigned to demonstrate the potential of the students to fully understand and apply the code provisions.

The problem of teaching such a comprehensive course is the selection of an appropriate textbook. This course includes several topics such as strength of materials, statics, structural analysis, reinforced concrete, and steel design. Some of these topics can be found in textbooks that were previously used in other courses. This narrowed the selection to a textbook that includes both steel and concrete design and the corresponding codes. To overcome this problem, the necessary information for the course was developed by the instructor and a full set of notes was distributed to the students to let them smoothly cruise through the course contents. The design codes were made accessible to the students by having several copies available in the department/ school library for reference.

Course Outline

The course outline was carefully designed to guide the students step by step throughout the complete design of a steel/ concrete building. This will enable the students to acquire the necessary practical experience in structural engineering practice. During fourteen weeks, the time span for the course, the course outline was designed to proceed as follows:

A. Week #1

1) Place of Structural Discipline in Civil Engineering

This section provides an introduction to structural engineering. It also discusses the constraints and restrictions that control the design of any system as well as the standards that satisfy both safety and serviceability.

2) Types of Buildings and Building Codes

This section deals with the general building codes in the USA and the steel/concrete design codes. It also provides a general idea of zoning ordinances and state regulations and their influence on structural analysis and design.

3) Types of Loads and Loads Calculation

This is a vital part that includes the definition of all types of loads acting on any structural system as well as the method of their calculation. This includes the minimum design live loads and the code allowance for live load reduction along with the different types of dead loads.

B. Week #2

1) Steel/Reinforced Concrete Term Project

The term project will be discussed in details later in this paper. Generally speaking, the students will design a real-life building including both superstructure and foundation. At this point, the instructor will review all principles for structural drawings. The students will then start drafting all framing plans and calculating all columns loads based on the information given in the previous week. Using a simple type of foundation, the isolated footings, the students will be able to draw the foundation plan showing all the necessary information including footing sizes.

The students will spend about four weeks to finish up all these tasks. During this period, the instructor will be reviewing the principles of statics and strength of materials and will answer all questions related to the project.

C. Week #3

1) Fundamentals of Mechanics of Materials

In this section a general review of the principles of statics will be emphasized. This will include the definition of all types of forces and moments, the classification of all types of supports, the study of the free bodies of forces, and the principles of internal/external equilibrium. The students should be capable at this stage to apprehend the philosophy of the normal force, the shear force, and the bending moment diagrams along with their applications.

D. Week #4

1) Geometric Properties of Sections

This section provides a general review of the properties of sections. This includes the centroid and the moment of inertia of composite sections, the radius of gyration of sections, the statical moment of areas, and the torsional constant of sections. This information is essential for the introduction to the principles of strength of materials.

E. Week #5

1) Structural Behavior of Members Under The Effect of Loads

This section provides information about the different types of stresses including axial stresses, shear stresses due to shear forces/torsional moments, bending stresses, and bearing stresses. A discussion about the properties of steel and concrete and a study of their stress-strain relationships will follow.

2) Introduction to the Leading Design Codes

This section introduces the leading design codes in the USA for the steel and concrete design. By presenting the Allowable Stress Design method for steel and the Ultimate Strength Design method for concrete, the student will understand the philosophy behind both methods. This will enable the student to easily comprehend any design code as needed in the future. For instance, the timber design code follows the allowable stress design while the steel design is geared now towards the ultimate design.

F. Week #6

1) Structural Analysis of Trusses and Frames

The main purpose of this section is to introduce the types of trusses and frames used in the different types of construction. This includes a discussion of the wind and seismic frames and bracing in structural systems. The analysis of trusses will be reviewed using both methods of sections and of joints. Also, a general discussion of the analysis of frames will be considered.

2) Study of Influence Lines

This section includes the study of influence lines and their application in structural design. The influence lines of shear and bending moments in beams and those of truss members forces will be presented along with their practical use in structural design.

G. Week #7

1) Follow-Up on Term Project

At this stage the instructor should make sure that the students are on schedule and are ready to start the design stage in the following weeks. The project is periodically monitored during the last four weeks and assistance is provided as needed. The instructor will ensure that every student has completed the necessary work to start the project; framing plans should be drafted, column loads calculated, and all beams critical shears and moments calculated. Sections and details will be provided to assist the students to finish up their work.

H. Week #8

1) Introduction to the Design of Steel Members

This week announces the birth of the design stage of this course. Although it seems that this is a late starting point for design, I think that the revision that took place is vital and will have a great impact on the students and on the way they will perceive the code's provisions.

At first, the students will learn about the different code sections and how to search for any information in the steel manual. Then, they will get familiarized with the various steel sections, their geometric and structural properties, and their practical use in building construction. The principle of shop drawings and the sequence of all the common construction activities will be discussed. The factor of safety approach will be explained and the allowable stress design will be introduced.

I. Week #9

1) Design of Steel Axial Members

In this section the students are exposed to the design and analysis of tension and compression members as per code provisions. The design of tension members is covered based on the gross and net section area. Column tables are presented for compression members with the code provisions for the allowable stresses and slenderness consideration. At this stage, The students should be capable of designing all the steel columns and axial members in the project.

J. Week #10

1) Design of Steel Beams

At first, the criteria governing the design of beams are presented. These include bending and shear stresses and live load deflection. Moment tables will be introduced along with the allowable stresses of bending in different planes. Deflection calculations will be applied using the standard beam formulas. Unbraced beams are defined and the design requirements and approach will follow. The use of design charts and the allowable stresses of unbraced beams are presented in detail. The design of composite section beams will be introduced and demonstrated using a commercial software package.

2) Design of Beam-Columns

Code provisions are provided for the design of members subjected to both axial and bending stresses. Design equations and applications are reviewed along with the importance of their applications.

3) Design of Base Plates

This section will introduce and discuss the principle of bearing and bending of plates. This introduction will help the students to visualize the principle of bearing capacity of soils and the design of footings.

K. Week #11

1) Introduction to the Design of Reinforced Concrete Members

In this section the students are exposed to the ultimate design approach. The overload and the understrength factors are presented for the different types of loading. The principle of factor of safety is discussed and compared to that used in the working stress design.

2) Analysis of Continuous Beams

Since most of the beams in concrete structures are designed and built as continuous beams, it is necessary to introduce a simplified method for the analysis of these beams. The Three-Moment Equation is a simple tool used for this purpose. The rotation of beams is introduced along with tables that show the value of rotation for several loading cases. Examples are studied to investigate the critical values of bending moments and shear forces in continuous beams.

L. Week #12

1) Analysis of Concrete Beams

In this section, the stress distribution is studied based on the working stress and the ultimate strength design methods. The location of neutral axis in concrete sections and the principle of internal moment capacity are introduced. Code provisions for the minimum and maximum reinforcement in a section are included with a presentation of the balanced condition of concrete sections.

2) Design of Rectangular Sections

This section deals with the design of rectangular sections and includes the determination of the section's width, height, and the area of steel. Two methods are presented using a step-by-step approach by assuming two of the three design unknowns. The first method assumes the area of steel as a percentage of the maximum allowable area recommended by the code and assumes an approximate relation between the section dimensions. The second method assumes both section dimensions to calculate the area of steel required. Tables and charts are provided for the second method for different steel and concrete strength values.

3) Design of One-Way Slabs

The design of slabs proceeds exactly in the same way as per the second method shown above since the slab is designed for a unit width and its thickness is determined based on the minimum code provisions. The students are exposed to the design of continuous slabs using the moment factors provided by the codes.

M. Week #13

1) Design of T-Section Beams

This section starts with the introduction of T-sections and their similarities with rectangular sections. A step-by-step procedure is provided for the complete design and investigation of T-sections.

2) Analysis of Shear in Concrete Beams

This section includes the study of shear aspects in concrete beams. The shear resistance in concrete sections is studied according to the code provisions. Shear reinforcement requirements are determined based on the ultimate shear in beams. At this stage, the students can wrap up the design of all concrete beams and slabs in the project.

N. Week #14

1) Design of Concrete Tension Members

Although concrete does not have any capacity to carry tension loads, tension concrete members do exist. The design of tension members is provided with some practical examples.

2) Design of Concrete Columns

This section ends the design stage of the project where the students will design all the concrete columns in the project. Braced and unbraced columns will be covered in details, and the effect of slenderness will be briefly explained to introduce the design and analysis of beam-columns.

3) Design and Analysis of Beam-columns

This advanced topic is introduced to explain the effect of wind, seismic, and slabs/beams unbalanced moments on the capacity of columns. Software packages are used to fully demonstrate the analysis.

Term Project

The term project is a real-life project that was selected to include all design aspects covered in this course. The following subsections provide a complete description of the project and a precise definition of all requirements.

A. Project Description

A structure is to be built to accommodate six levels of classrooms and school facilities. The floors usage and construction are described as follows:

- The basement is a 6 inch slab on grade that will support all the mechanical equipment in the building.
- The first floor includes the lobby, cafeteria, kitchen, and all offices. The structural system is a one-way slab supported on beams and girders. The whole floor is supported on concrete columns which will pick up also the steel columns supporting the floors above.
- The second floor includes the library and computer facilities. The floor construction, which is typical for all floors above, consists of a 2-inch normal weight slab on a 3-inch 19GA metal deck.
- The third and forth floors are designated for all classrooms.
- The roof is designed as an assembly area with 2 inches Terrazo finishing. A roof slope of _"/foot is shown on plan to allow for water drainage.

A set of drawings is attached to show the architectural features and structural aspects to be considered in the structural design as explained below:

- All exterior and interior columns are allowed only on lines where walls exist. - A canopy will be provided at the

main entrance and is supported by two diagonal ties at column lines C and D.

- The canopy and stair roof construction consist of a 1_ inch 20GA metal deck topped with membrane and insulation and a 2 inch layer of gravel.
- All interior partitions are 6 inch light aggregate block.
- Two cases of loading will be considered to design the canopy roof; 35 psf snow load and 25 psf upward net wind suction.

B. Project Requirements

1. Select a structural system for each floor showing the location of columns and beams along with all grid dimensions. Dimensions are given in terms of "H" and "L" whose values are different for each student.
2. Give details of all the design loads calculations. Dead loads include slab construction, floor finishing, ceiling, insulation, floor beams, and partitions. Provide a *Live Load Table* showing all live loads as per code provisions.
3. Design all steel columns using the Allowable Stress Design (ASD) Method and the tributary area method how all columns sizes in a *Column Schedule*.
4. Design all steel beams using the ASD Method. Do not reduce girders live loads.
5. Design the first floor slab and beams using the Ultimate Design Method. Show all reinforcement in a *Beam and Slab Schedules*.
6. Design the foundation using isolated footings resting on a soil with a minimum bearing capacity of 5 ton per square foot.
7. Give dimensioned framing plans for every floor, including the basement. Show all design information, the type of floor construction, different elevations, and strength of materials used. Consider the basement elevation at 0'-0".
8. Design a typical interior base plate.
9. Detail the following conditions using an appropriate scale:
   - Typical steel column to concrete column connection
   - Typical section of the foundation wall
   - Typical elevation of a concrete beam at the first floor

Discussion

The course outline of any subject and the type of work assigned in that course are of great importance to its success. The extent of success of any course depends mainly on the selection of the topics that will be covered in that course as well as their sequence.

The course described in this paper, Structural Design, was designed in such a way to go smoothly through the design codes in a logical sequence while applying examples from real life practice. This course ran successfully as judged by the instructor and students. The students' overall evaluation for this course was near the 95% mark. The main reason for this success is that both the course materials and the design project went in parallel during the whole semester. In addition, the amount of work involved in this project was uniform throughout the whole semester. Also, the fact that every student had the same exact project, with different dimensions and elevations, helped to unify the type of effort involved in the project. Furthermore, open discussions and various approaches taken in the project provided the students with a great deal of information and enhanced their ability of analysis.

The use of design software was limited to particular parts of the project to allow the students to have both types of experience; the design with and without computer software. Both hand and Computer Aided Drafting (CAD) were also required. Floor plans were drafted by CAD for simplicity while sections and details were hand drafted.